

# Functional Disability of the Wrist: Direct Correlation With Decreased Wrist Motion

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**Purpose** Motion-limiting wrist procedures have demonstrated both efficacy and reproducibility as a treatment for alleviating painful wrist conditions, but the reduction of pain achieved is necessarily accompanied by a marked loss of wrist motion. However, no study demonstrates a functional difference between variable degrees of wrist motion. The hypothesis of this study is that wrist motion is directly correlated with functional ability.

**Methods** Using a prospective, randomized, crossover design, we randomized 42 men and women above 45 years of age with normal wrists to wear both a partially restricted and a highly restricted splint for 24 hours each. Serving as their own controls, objective and subjective outcome measurements were taken at baseline and after each of the 2 splinting periods. The specific measurements included range of motion parameters (flexion/extension, radioulnar deviation, supination/pronation, circumduction), subjective surveys (Disabilities of the Arm, Shoulder, and Hand; Patient Rated Wrist Evaluation; and Modern Activity Subjective Survey), and an objective timed test (Modern Activity Timed Test; MATT).

**Results** The simulated flexion/extension arc of motion for baseline, partially restricted, and highly restricted conditions were 138°, 58°, and 20°, respectively. Median Disabilities of the Arm, Shoulder, and Hand scores for the 3 conditions significantly increased from 1.8 to 14.4 and 20.8 ( $p < .01$ ), respectively. In addition, Patient Rated Wrist Evaluation results increased from 2.5 to 16.4 and 27.1, and the Modern Activity Subjective Survey results increased from 0.3 to 9.1 and 14.9 across restricted motion conditions. Modern Activity Timed Test results matched the perceived difficulty reflected by the subjective surveys, demonstrating significant increases in performance time for 6 of the 8 individual MATT items as well as significant differences for the sum of all tasks (MATT score) between the highly and partially restricted conditions.

**Conclusions** Use of low-profile splinting to restrict wrist motion demonstrates a direct correlation between restriction of wrist motion and functional disability. (*J Hand Surg* 2008;33A:485.e1–485.e9. Copyright © 2008 by the American Society for Surgery of the Hand.)

**Key words** Circumduction, functional activity, prospective, randomized, wrist arthroplasty.

A VARIETY OF WRIST SURGERY procedures performed to alleviate pain result in partial to total elimination of wrist motion. Historically, procedures resulting in total loss of motion have demonstrated efficacious and reproducible results,<sup>1–4</sup> whereas some surgical procedures that spare motion have suffered from high rates of complications.<sup>5–11</sup> Patients prefer retention of wrist motion,

presumably under the assumption that increased motion will yield increased functional performance; however, no studies have demonstrated a correlation between motion and function. On the contrary, previous studies have demonstrated the wrist's capability of performing a wide variety of daily activities even under the most highly restricted motion conditions.<sup>12</sup> Moreover, other recent studies specifically examining the difference between degrees of motion restriction have shown no functional difference between partially and highly restricted wrist motion.<sup>12,13</sup>

The purpose of our study was to conduct a prospective, randomized, crossover trial using 2 restricted conditions to evaluate the impairments of limited wrist motion. In contrast with previous studies, we used volunteers from the same age cohort as the arthritic patient population, custom-made low-profile splints, and developed new tools to assess functional impairment of both circumductive wrist motion and commonplace tasks. We believe that modifications in our protocol and study design relative to prior research have the potential to demonstrate differences that were otherwise unobserved. Use of an age-appropriate arthritic population for our cohort increases the likelihood that our conclusions are clinically relevant to the patient population. In addition,

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use of custom-designed wrist splints to allow circumferential motion overcomes limitations of hinged-wrist splints used in prior studies that can only move in uniplanar angles. We also believe that current evaluation tools do not adequately measure the broad variety of tasks that individuals perform throughout a day, and we developed 3 new and unique tools with the purpose of increasing the sensitivity of detecting subtle functional differences between restricted motion conditions. Lastly, by using a protocol similar to past studies, our results can be directly compared with prior research in the field. Our hypothesis is that restricted wrist motion directly correlates with functional impairment.

## MATERIALS AND METHODS

Between June and August 2006, we recruited by Internet advertisement right-handed men and women above 45 years of age with no history of hand or wrist impairment. Exclusion criteria included current complaints or history of wrist pain and trauma and left-hand dominance. Left-hand dominance was excluded to achieve consistency in specific task assessments. Institutional review board approval was received (no. 2006-P-000051/1, March 29, 2006), and written informed consent was obtained from all participants. Participants received modest monetary compensation for their time.

### Protocol

The study consisted of 3 assessments during a 48-hour protocol; each assessment included range of motion testing, 3 subjective surveys, and a functional timed test. Two randomization protocols were implemented for each subject using a computerized random number generator. Each subject was randomized to wear 1 of the 2 wrist splints (highly restricted or partially restricted) on his or her right wrist between days 0 and 1 and to wear the other splint between days 1 and 2, followed by an assessment on each day. In addition, subjects were randomized to obtain baseline assessment values (no splint) either on day 0 before the first splint; on day 1, between removing the first splint and applying the second; or on day 2, after removing the second splint. The randomization schemes among splint order and baseline assessments had 2 unique purposes. By randomizing splint order, we reduced the effects that learning and accommodation to splint-wearing would have while wearing a second splint. In other words, we believed that volunteers could reasonably expect to functionally perform better after 24 hours of wearing a splint because of accommodation. Thus, our randomization protocol prevented this effect from influencing the outcomes of one splint more than the other. In addition, by randomizing baseline assessment points, we attempted to reduce a learning effect on the outcomes assessment. Without randomization, one would expect artificial improvements on days 1 and 2 from familiarity with the tests, having performed them once and twice before, thus influencing outcomes. Our primary end point was to evaluate the limitation of wrist function between a partially restricted and



**FIGURE 1:** Example of right arm with the partially restricted splint, secured by 3 Velcro straps, and signed by a researcher on an outer layer of circumferential tape to verify subject compliance.

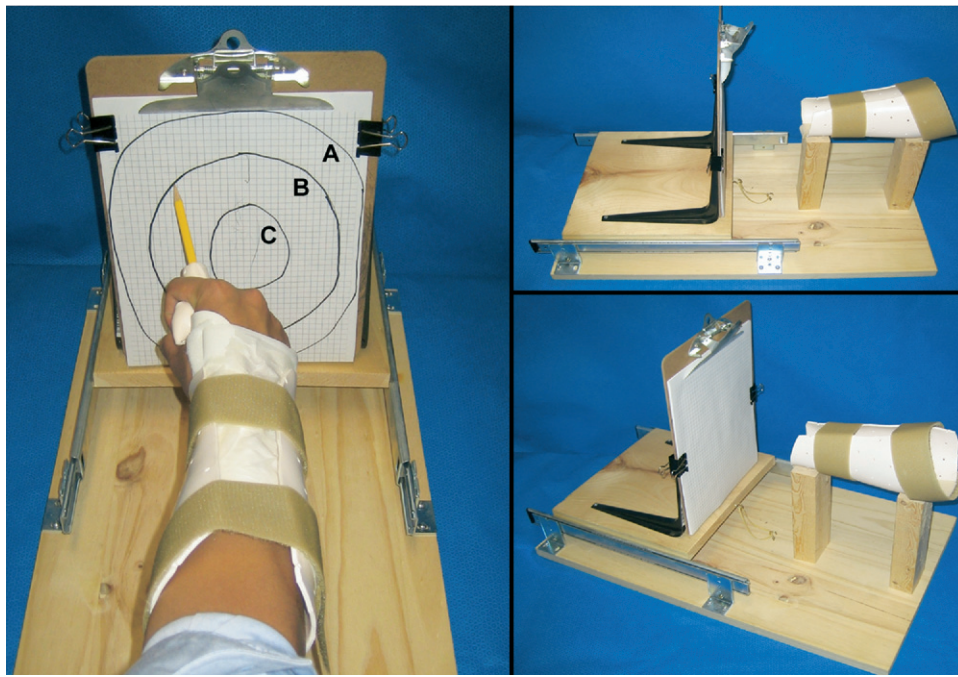
a highly restricted range of motion condition. Secondary end points included measuring and comparing subjective perception of function under each condition relative to objective data.

### Splinting

Wrist motion was restricted for each subject by 2 customized splints (Alimed, Dedham, MA). The 2 splints were of comparable form, shape, and weight but differed in the stiffness of the construction material, thereby creating 2 restrictive states. The partially restrictive splint was made of hypoallergenic closed-cell foam and designed to simulate the motion parameters of a motion-restricting wrist procedure. The highly restrictive splint was made from heat-sensitive moldable plastic (Aliplast, Dedham, MA) and designed to simulate the motion of a greatly motion-limiting procedure (15% of normal) compared with the foam splint, which simulates a partial motion-limiting procedure (42% of normal). Both splints were secured with 3 Velcro straps attached to low-profile rivets and wrapped with tape to create an unobtrusive design (Fig. 1). Comfort was an important concern, and steps to decrease splint irritation included use of 3 different splint sizes, cotton stockinettes under each splint, moleskin for sore spots and irritation, and custom-fitted openings for the thumb and palm. Once properly fitted, splints were less than 5 mm above the skin surface and had relatively minimal hindrance to hand function. Subjects were instructed not to remove the splint for 24 hours, and bathing could be accomplished by wrapping the splint in a plastic bag. Compliance was verified by a signature on the outer layer of circumferential tape, and by this measure there were no incidences of splint removal.

### Measurements of Range of Motion Parameters

Use of splinting as a model for motion-sparing and motion-ablating procedures was verified through measurements of range of motion parameters taken before and after each 24-hour period. Wrist flexion/extension, radioulnar deviation,



**FIGURE 2:** The custom-built device used to measure the circumductive wrist motion. The 3 circles are representative of the motion allowed under normal (circle A), partially restricted (circle B), and highly restricted (circle C) splinted conditions. The circles were drawn by the subject in pencil but have been outlined with marker for clarity.

and supination/pronation were all measured using a standard goniometer by a single investigator (O.I.F.). The fourth motion axis recorded was wrist circumduction, or circular wrist motion. Circumduction was measured using a custom-designed and custom-built device (Fig. 2). To obtain a measurement, subjects placed their forearm upon the support while holding a molded-plastic device that supported a pencil pointing along the axis of the forearm shaft. Velcro straps were used to secure the forearm and prevent lifting or twisting during the motion. As subjects made a circular motion with their wrists, the pencil drew a circle on standard graph paper, reflecting the limits of their motion arcs. Circumductive wrist motion was recorded as the area of the shape, measured in inches squared, drawn on the paper with the pencil length adjusted to a fixed distance of 16 cm from the volar wrist crease (Fig. 2).

### Subjective Surveys

Three subjective surveys were used to measure subject satisfaction under each splinted condition. Two were validated surveys: the Disabilities of the Arm, Shoulder, and Hand (DASH; see <http://www.dash.iwh.on.ca/>) and the Patient Rated Wrist Evaluation (PRWE), both of which have demonstrated reliability for measuring subjective reporting of wrist impairment.<sup>14-16</sup> The third was a study-specific survey titled the Modern Activity Subjective Survey (MASS), which examined the performance of commonplace activities, including many not included in either the DASH or PRWE. The DASH was developed in 1996<sup>14</sup> and the PRWE in 1998,<sup>15</sup> and neither includes questions about

digital technology, computers, cell phones, and other small electronic devices, which are becoming increasingly relevant in commonplace activities. The rationale for developing the MASS was to include these behaviors, which, for many individuals, are of substantial importance. The format of the MASS asks an individual to rate his or her ability to perform 10 common actions, most of which are not included on the DASH and PRWE (Appendix A; this appendix may be viewed at the *Journal's* Web site, [www.jhandsurg.org](http://www.jhandsurg.org)). Tasks are rated on a scale from 0 to 10, and results are recorded as the sum of all scores. The sum score is from 0 to 100, similar to the DASH and PRWE.

### Functional Timed Tests

Objective measurements of motions have previously been examined in studies similar to this one<sup>13,17</sup>; however, no studies have quantified and measured the functional effects of restricted wrist motion on commonplace modern activities. In this study, we define commonplace activities as those that may be performed multiple times per day, and we developed a new set of tasks to directly assess the functional ability of subjects executing these contemporary activities. The set of 8 tasks (Appendix B; this appendix may be viewed at the *Journal's* Web site, [www.jhandsurg.org](http://www.jhandsurg.org)) was named the Modern Activity Timed Test (MATT) and is not validated. The MATT closely reflects tasks included in the MASS, which were selected for complexity, inclusion of some newer technology not included in previous surveys, high frequency of performance, and a distinct beginning and end point for objective quantitative purposes. Each task was

TABLE 1: Motion Parameter Measurements According to Splinted Condition

Measurement	Baseline	Partially Restricted	Highly Restricted	p Value (Wilcoxon Test)
Flexion (°)	74 (60–77)*	22 (13–32)	0 (–5–5)	<.01†
Extension (°)	64 (56–70)*	36 (30–43)	20 (15–22)	<.01†
Radial deviation (°)	25 (20–30)*	16 (11–22)	6 (3–10)	<.01†
Ulnar deviation (°)	38 (33–44)*	25 (20–28)	15 (12–19)	<.01†
Circumduction (in. <sup>2</sup> )	74 (68–81)*	54 (42–58)	27 (19–36)	<.01†
Supination (°)	90 (80–90)	83 (75–90)	90 (78–90)	.18
Pronation (°)	90 (90–90)	90 (80–90)	90 (80–90)	.41

Note: Data represent the median and the interquartile range.

\*Statistically significant compared with both partially and highly restricted conditions.

†Statistically significant differences between partially and highly restricted conditions.

recorded as an average time to correctly complete 3 uninterrupted attempts, and the MATT score was recorded as a sum of the average times (seconds) to complete each of the 8 tasks. All timed measurements in this study were assessed by a single investigator (O.I.F.).

### Statistical Analysis

Subjective survey results gathered from the DASH, PRWE, MASS, and MATT functional tests for baseline (no splint), partially restricted, and highly restricted splinting conditions were compared using paired *t*-tests and described in terms of the mean and standard deviation, as these variables conformed to a normal (Gaussian-shaped) distribution. Range of motion variables (flexion/extension, radioulnar deviation, supination/pronation, circumduction) were compared among the splinting conditions using the nonparametric Wilcoxon signed rank test, because range of motion variables show marked skewness and therefore are summarized by the median and interquartile range.<sup>18</sup> To adjust for multiple comparisons, the conventional *p* value was adjusted using a Bonferroni criterion of  $p < .017$  (ie, .05 divided by 3) to protect against type I errors.<sup>19</sup> Statistical analysis was performed using the SPSS software package (SPSS ver. 14.0; SPSS Inc., Chicago, IL). All reported *p* values are 2-tailed. A power analysis indicated the sample size of 42 patients provided 80% power ( $\beta = .20$ ) for detecting differences of 25% or more with respect to each of the functional, motion, and subjective outcome measures based on the appropriate parametric or nonparametric tests for paired analysis (nQuery Advisor ver. 6.0; Statistical Solutions, Saugus, MA).

### RESULTS

Of 58 individuals who responded and qualified for the study, 45 were scheduled for appointments. Two failed to show up to their appointments, and 1 was excluded for previously undisclosed arthritis, leaving 42 subjects included in the study. All were right-handed and tested on their right

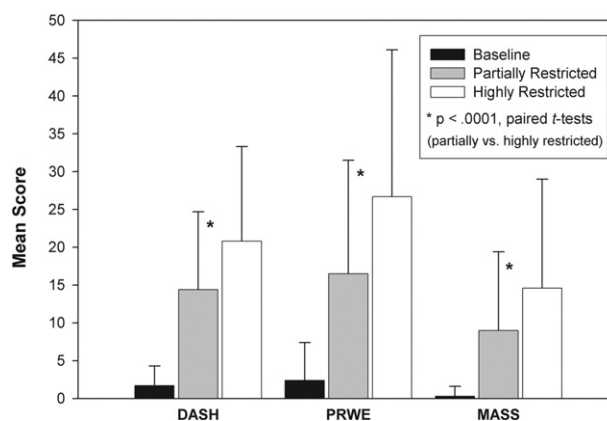


FIGURE 3: Subjective survey score results for the DASH, PRWE, and MASS under all 3 restricted conditions.

side. There were 25 women and 17 men with a mean age of 54 years (range, 45–69 years). Baseline and outcome measurements for motion parameters are listed in Table 1. Range of motion parameters for the partially restricted condition had a median flexion/extension arc of 58° and a median radioulnar deviation arc of 41°. The highly restricted condition had a median flexion/extension arc of 20° and median radioulnar deviation arc of 21°. Circumductive motion for the partially restricted wrist measured an average area of 54 square inches, and the highly restricted wrist measured an average of 27 square inches. These demonstrated statistical significance for 5 of the tested range of motion assessments ( $p < .001$ ). Supination and pronation were not restricted by either splint.

Baseline and splinted subjective survey results for each condition were collected, analyzed, and found to be statistically significant between groups (Fig. 3). Mean DASH scores were 14.4 and 20.8 for the partially restricted and highly restricted conditions and PRWE scores averaged 16.5 and 27.7, respectively. The newly introduced MASS survey

TABLE 2: Summary of Individual MATT Tasks According to Splinted Condition

MATT Task	Baseline (s)	Partially Restricted (s)	Highly Restricted (s)	p Value (Paired <i>t</i> -Test)
Item 1: dial a cell phone	9.5 ± 2.1	9.7 ± 2.2	10.6 ± 2.7	.04†
Item 2: take \$1 from wallet	6.0 ± 1.6*	6.5 ± 1.5	6.9 ± 1.4	.021
Item 3: write a check	26.1 ± 7.9*	27.9 ± 7.2	28.4 ± 7.5	.14
Item 4: plug in a USB drive	2.6 ± 0.6*	3.1 ± 0.7	3.5 ± 0.7	<.01†
Item 5: fold a T-shirt	8.4 ± 3.1*	9.1 ± 3.1	9.9 ± 3.5	.13†
Item 6: take a photograph	5.7 ± 1.1*	6.2 ± 1.1	6.6 ± 1.1	.08†
Item 7: type a sentence	15.8 ± 4.8*	17.3 ± 5.2	19.0 ± 5.7	.01†
Item 8: navigate the Internet	19.0 ± 2.9*	20.5 ± 3.1	22.4 ± 3.8	.02†
MATT score	92.2 ± 15.2*	99.5 ± 15.0	106.5 ± 16.9	.01†

USB, universal serial bus.

Note: Data represent mean ± SD.

\*Statistically significant compared with both partially and highly restricted conditions.

†Statistically significant differences between partially and highly restricted conditions.

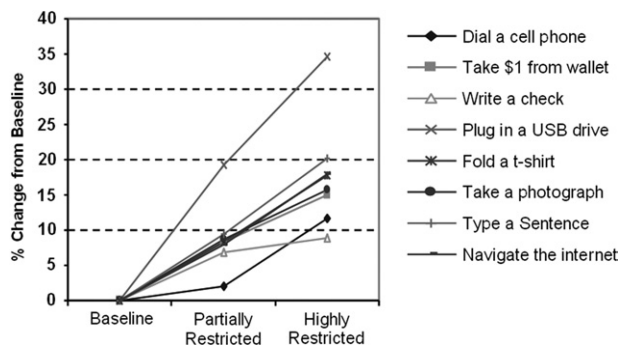


FIGURE 4: Modern Activity Timed Test scores, represented as the percentage change from baseline for each of the 8 individual tasks for the partially restricted and highly restricted splinted conditions. The average change for the partially restricted condition was 8%, and the average change for highly restricted condition was 16%. USB, universal serial bus.

also demonstrated a significant difference between the 2 splinted conditions with scores of 9.0 and 14.6, respectively.

Modern Activity Timed Test results matched the perceived difficulty reflected by the subjective surveys, demonstrating increases in performance time with increased survey scores. Individual MATT scores showed a significant increase in performance time (relative to the un-splinted condition) for all tasks ( $p < .017$ ) except for items 2 (taking \$1 from a wallet,  $p = .021$ ) and 3 (writing a check,  $p = .142$ ). The total MATT score, reported as a sum of the individual 8 tasks, was significantly different between the highly and partially restricted conditions, and average MATT task results for each item are reported in Table 2. In addition, the mean percentage increase from baseline for MATT task completion time for the partially restricted splint was 8% (range, 2% to 19%), and the highly restricted

splint demonstrated a 16% increase (range, 9% to 35%) as shown in Figure 4.

Outcome measurements for the DASH, PRWE, and MASS were compared using Pearson correlations to assess for associations with age, and none were found to be related ( $r$  values all  $< 0.20$ , all  $p > .10$ ). In addition, Student's  $t$ -tests were used to evaluate whether survey outcome scores showed differences based on gender or order of splinting, and no significant differences were detected (all  $p > .10$ ). This analysis revealed that the differences between partially and highly restricted conditions were independent of age, gender, or order of splinting.

## DISCUSSION

The goal of establishing the limits of functional wrist motion has evolved in 3 stages.<sup>12</sup> The first studies, in the early 1900s, perceived wrist function as a direct and linear correlation of maximum wrist motion. Experiments measured the maximal amount of wrist angulation in any one direction and assigned that value as the functional motion; however, this perspective of wrist function was criticized for lack of experimental data and was later abandoned.<sup>12</sup>

The second approach to assessing functional wrist motion was to view functional motion relative to that used during tasks. With this in mind, experiments were conducted measuring wrist motion while a subject performed a variety of activities of daily living (ADLs). Functional motion was reported as the maximal angulation during each activity. Results from 3 prominent studies demonstrated the flexion/extension (degrees) required for most ADLs to be  $10^\circ/35^\circ$ ,<sup>20</sup>  $5^\circ/30^\circ$ ,<sup>21</sup> and  $54^\circ/60^\circ$ ,<sup>22</sup> with the wide variation due to differences in ADLs tested during the assessments, the methods of measurement, and the perceived performance level.<sup>13</sup> The failure of this approach, as pointed out by Nelson, was the assumption that maximal motion used is

the maximal motion needed for any such task. For example, one may not need the 94° flexion/extension arc used while tying a necktie/scarf to effectively complete the task.<sup>22</sup> In addition, daily activities were arbitrarily chosen for the studies, yet the motion results were extrapolated to be generalized for all activities. Common to these earlier studies were hygiene and occupational ADLs such as combing hair, dressing oneself, eating with utensils, or turning a doorknob.<sup>12,20–23</sup> However, the motion used to accurately complete those tasks may be substantially different from the motion required for other activities not included in these earlier studies, such as talking on a mobile phone, typing on a computer keyboard, or using a computer mouse. The last is especially important as minor variations in accuracy and precision while using a computer mouse can have profound effects on overall function, a characteristic not necessarily true of other activities.

The third and current approach, used by Nelson to measure functional wrist motion, relates function to required motion. That is, to what degree can the wrist perform tasks under restricted conditions? Nelson's study assessing more than 125 ADLs demonstrated that even while using a custom-made splint to restrict wrist motion to "as close to zero as possible," many activities can still be performed accurately. In his study, the 7 most difficult activities to perform under highly restricted conditions included fastening a bra, dusting a low surface, washing one's back, writing one's name, using a manual can-opener, handling a sharp knife, and using a manual egg-beater.<sup>12</sup> These activities are not equally relevant to all patients weighing their options between 2 functionally limiting procedures, and even Nelson noted that "all ADLs are not equally important." Thus, even the most comprehensive of studies had difficulty establishing a standard for functional wrist motion generalizable to all patients.

All 3 approaches to determining the limits of functional wrist motion have limitations in their assumptions about wrist function. The most recent study in this field establishes that many ADLs can be successfully performed even under the most highly restricted motion conditions of the wrist. This was achieved by asking small samples of volunteers to subjectively rate their difficulty performing more than 125 activities under variable degrees of motion restriction. Although this study concluded that all subjects could perform all tasks even under the most highly restricted conditions, the authors "do not conclude that . . . greater ROM [is] not preferred" and acknowledge that "larger ranges of motion are preferable."<sup>12</sup> Nevertheless, the literature has left physicians and patients without substantive evidence of the functional differences and limitations of partially and highly restricted wrist motion. To address this deficiency in the literature, a new study design was required that focused on demonstrating a comparative difference between 2 restricted motion conditions rather than establishing a value universally considered to be the limit of acceptable function. In addition, whereas earlier studies tested a broad range of ADLs, occupational activities, and recreational activities, the demographic data and daily activities of current

wrist surgery patients are variable and have changed since the publication of previous studies. New studies were needed to test the functional outcomes in a modern world with an active population.

Different methods of assessing objective functional outcomes assessments have been developed and validated, with the most prominent being the Jebsen Hand Function Test.<sup>17</sup> This test, developed in 1969 to assess hand function, times patients while performing 7 tasks: writing, simulated page turning, lifting small objects, simulated feeding, stacking checkers, lifting large light objects, and lifting large heavy objects. Because no other validated function test assessed the more modern activities evaluated in our study, we designed and used the MATT as a functional outcomes assessment for 8 specific commonplace modern activities. We found in our study that the MATT was able to detect subtle differences in a volunteer's ability to perform timed tasks with varying degrees of motion restriction.

Our study design measured functional outcomes of restricted motion by using a comparison protocol to establish differences between conditions. The partially restricted splints limited subject motion to within the range of published literature values for surgical procedures such as total wrist arthroplasty, proximal row carpectomy, and partial wrist arthrodesis.<sup>5,24,25</sup> Similarly, the highly restricted splints were designed to mimic a highly restricted motion wrist. Although intended to result in zero wrist motion, the highly restricted splint condition used in this study allowed for some undesired movement because of the challenges of controlling the wrist completely with an external splint. The discrepancy between the motion achieved by our highly restricted splints versus a motionless wrist suggests that our results may actually underestimate the degree of functional limitation by a motion-eliminating procedure. Our results of functional tests on splinted volunteers suggest that patients with similar degrees of motion restriction may have an objective and quantifiable functional advantage over patients with highly restricted or complete loss of motion. It must also be noted, however, that all subjects in both highly and partially restricted motion conditions had a surprisingly high degree of functional motion, suggesting that a direct correlation does not exist between loss of motion and loss of function.

Only 1 other study has examined the functional differences between partially restricted and highly restricted wrist motion. In 2003, using a protocol similar to our own, Adams et al conducted an experiment in which subjects were required to wear 2 splints restricting wrist motion for 24 hours each and concluded that "perceived disability from reduced wrist motion appeared greater than measured functional loss using common physical tests and outcome surveys."<sup>13</sup> From this conclusion and our hypothesis that wrist motion correlates with functional ability, we believed that current surveys may not be adequately designed to test the commonplace modern activities influenced by reduced wrist motion, and we included the MASS and MATT tests to evaluate activities such as typing on a keyboard or navigating the Internet with a computer mouse. Moreover, use of a hinged wrist splint by Adams et al may have

influenced that study's conclusion by adding excess weight and girth while restricting radioulnar and circumductive motion. The splints used in our study allowed for wrist motion in all planes and more closely mimicked the physiologic motion and weight after a motion-sparing wrist procedure. The inclusion of circumduction evaluation in our study was intended to reflect differences between flexion/extension and radioulnar deviation arcs relative to true circumduction motion and to analyze those results relative to functional timed tasks. However, in the case of this study, the splints allowed for full rotational motion, and uniplanar motions were qualitatively similar to circumduction motion results. One other source of potential bias in the Adams protocol included 21 subjects with a mean age of 21 years. Our study enrolled twice the number of subjects (42) with a mean age of 54 years, thereby serving as an age-appropriate representation of an arthritic patient population most likely to be candidates for these procedures and further reducing the possibility of confounding factors from a sampling bias. We believe our study adds to the growing body of knowledge designed to effectively compare the functional differences between partially and highly restricted wrist motion.

One limitation of our study is use of the nonvalidated MASS and MATT tools to quantify subjective reporting and objective timed task measurements. The most popular validated surveys include the DASH and PRWE, and the most popular validated timed test is the Jebsen Hand Function Test.<sup>17</sup> As noted previously, past studies using the DASH survey have neglected to find subjective evidence that moderate motion restriction results in clinically important impairments of functional ability.<sup>12,13</sup> However, as discussed above, the limitations of prior studies led us to evaluate similar motion restriction conditions using new tools with the potential to better characterize differences that were otherwise unmeasured and unnoticed. Our findings are different from prior studies and demonstrate both statistically significant ( $p < .01$ ) and clinically important differences in DASH scores between restricted conditions. The DASH has a minimum clinically important difference (MCID) of 15 points, reflecting the smallest change in score that is considered to be important.<sup>26</sup> By these criteria, only the highly restricted motion condition results in clinically important functional differences from baseline values. Interestingly, we found that our results with the PRWE and new MASS test yielded generally similar results compared with the DASH, however no MCID has yet been established for either survey. Thus, whereas the changes between partially and highly restricted motion are statistically significant, the clinical implications of these results are unclear. Because the criteria for clinical significance are personal and variable among individuals, we leave the interpretation of these results to be made by physicians and patients on an individual basis.

Although use of standardized tests prevents us from making generalized conclusions for all wrist functions, the

MATT evaluation allowed us to demonstrate at least 6 activities that do have a statistically significant difference between restricted motion states. Because timed tests are also limited by the fact that most people do not type "1 sentence," pull out "1 dollar," or open a Web browser 1 time while using a computer, these brief, controlled tests represent disabilities of commonplace tasks that may imply clinically important alterations in a person's ability to function throughout an entire day. For example, one individual may regard a 35% increase in typing time to be clinically irrelevant, whereas to another person that may have important functional implications. The distinction between statistically important results is based in mathematics and objective criteria, but defining results as clinically significant is less concrete. Because the MCID has not yet been established for the MATT as it has been for other surveys,<sup>26</sup> we believe the clinical implications of our findings must be interpreted on an individual basis. The authors also recognize that functional ability may not always be appropriately measured by time and that more subtle changes including accuracy, precision, and long-term strain likely play a important role in the overall function of many tasks. Use of more sophisticated outcome measures in the future will undoubtedly take these additional functional assessment measurements into consideration. Lastly, because study subjects served as their own controls for the same set of standardized tasks, our study did not require the establishment of standardized values to compare against task performance in each condition. Thus, use of a novel set of tools should not affect the reliability of our results. Rather, the development of these tools gives researchers additional insight when assessing hand and wrist function in an era of increasing technology requiring frequent, subtle, and precise wrist motion. We found the MASS, MATT, and circumduction to be useful for measuring aspects of hand and wrist function never before described in the literature. Additional research is required to establish the validity and reliability of these new tools.

A second limitation of our study is use of an external splint to simulate the motion outcomes of surgical procedures. Because it is difficult to randomly assign patients to 1 of 2 motion-limiting wrist procedures, we believe that low-profile splints that were comfortable, noninvasive, and circumduction-permitting would serve as adequate models to test our hypothesis. In addition, although use of low-profile splints was designed to minimize the physical limitations of wearing an external device, the lack of a garment or glove while performing the baseline assessment may have influenced the functional outcome results measured between the unrestricted and restricted groups.

A final limitation of our study is the brief 24-hour splinting period used to approximate the functional abilities of patients with reduced wrist motion. Patients and volunteers alike may functionally learn and adapt to decreases in wrist motion over longer periods of time, and thus our 24-hour intervention may overestimate the

disability of each motion-restricted condition. In order to enhance their short-term adaptation and to help decrease this potential source of bias, all patients were given a sheet listing all activities included on the DASH, PRWE, and MASS and were encouraged to complete as many activities as possible during each 24-hour interval. This required us to use the DASH and PRWE outcome measures for less than the validated time period of 1 week; however, these surveys have been used for 24-hour interventions in other similar studies. In addition, use of each subject as his or her own control in this crossover design reduced the variability of any survey outcomes and allowed us to use the DASH and PRWE, as well as the MASS and MATT, during a brief intervention while minimizing the potential for systematic bias. A final consideration regarding the accommodation time of 24 hours is that both splints are affected equally. Thus, although an additional week of splinting intervention may result in an absolute improvement across functional assessments, the differential between the splinting groups is unlikely to change.

The major strength of our study is the ability to use each subject as his or her own control in a crossover design. This advantage, which could not be achieved even in a prospective randomized clinical trial, reduces a notable contribution of bias and adds strength to our findings. With custom-made low-profile splints, we were able to restrict wrist motion to variable degrees of limitation and quantify those values in 4 measurement axes (flexion/extension, radioulnar deviation, supination/pronation, and circumduction). Using volunteers as their own controls in a prospective randomized crossover design, we established that increasing wrist motion restriction yields incremental objective and subjective functional impairments with respect to the activities that we measured. We conclude that progressive loss of wrist motion under simulated splinted conditions creates incrementally significant functional limitation ( $p < .01$ ) and suggest that these conclusions may apply to patients with similar degrees of motion limitation.

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**APPENDIX A: MODERN ACTIVITY SUBJECTIVE SURVEY (MASS)**

Name: \_\_\_\_\_ Date: \_\_\_\_\_

For each of the following tasks, please rate your experience while performing them over the past day by circling the number that describes your difficulty on a scale of 0 to 10. A zero (0) means you did not experience any difficulty, and a ten (10) means it was so difficult you were unable to do it at all. If you cannot comment on your ability to perform a task, or if you do not know how to perform any of these tasks, please circle N/A.

Functional Task	No Difficulty	Unable to Do										
1. Type on a keyboard	N/A	0	1	2	3	4	5	6	7	8	9	10
2. Use a computer mouse	N/A	0	1	2	3	4	5	6	7	8	9	10
3. Dial a cell phone/telephone	N/A	0	1	2	3	4	5	6	7	8	9	10
4. Take a photograph with a camera	N/A	0	1	2	3	4	5	6	7	8	9	10
5. Pulling an item from a pocket/purse	N/A	0	1	2	3	4	5	6	7	8	9	10
6. Write a check	N/A	0	1	2	3	4	5	6	7	8	9	10
7. Take a dollar bill out of a wallet	N/A	0	1	2	3	4	5	6	7	8	9	10
8. Plug a cord into a power outlet	N/A	0	1	2	3	4	5	6	7	8	9	10
9. Do laundry/fold clothes	N/A	0	1	2	3	4	5	6	7	8	9	10
10. Type on a handheld device	N/A	0	1	2	3	4	5	6	7	8	9	10

N/A, not applicable.

**APPENDIX B: MODERN ACTIVITY TIMED TEST (MATT)**

Name: \_\_\_\_\_ Date: \_\_\_\_\_

- Take cell phone out of pocket/purse, dial own number, end call, and return to pocket/purse.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Take out your wallet, remove a dollar bill, and place it on the table.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Take out a checkbook, and write a check to yourself for \$10.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Plug a flash drive into a USB port.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Fold a T-shirt.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_

- Take out a camera from its case, hold it up to take a picture, and press the shutter.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Please type the following sentence on the computer, trying to avoid making any errors:  
***The lazy fox jumped over the white picket fence.***  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_
- Using the computer mouse, open Internet Explorer, go to [www.cnn.com](http://www.cnn.com), select the first headline on the right, and close the window.  
Attempt 1: \_\_\_\_\_ Attempt 2: \_\_\_\_\_ Attempt 3: \_\_\_\_\_  
Avg: \_\_\_\_\_  
*Note: Scoring is in seconds. Individual items are reported as the average of 3 uninterrupted attempts. The MATT score is reported as the sum of the 8 individual averages.*